How to use duplexers: Isolation requirements

Part 1—Duplexers in various forms isolate simultaneously operated transmitters and receivers. Here are some steps to follow to calculate the required isolation. Impedance differences make duplexers work.

By Brian J. Henderson, P.E.

You have just installed a base station and mobile radio system, perhaps for a customer.

Coverage is satisfactory from the base station to the mobile radios. Mobile-to-mobile range is limited. The customer wants to consider a repeater system to improve mobile range.

You want to serve the customer the best way you can. You buy a repeater. You install an antenna. You know you must buy a duplexer. Why? What does a duplexer do?

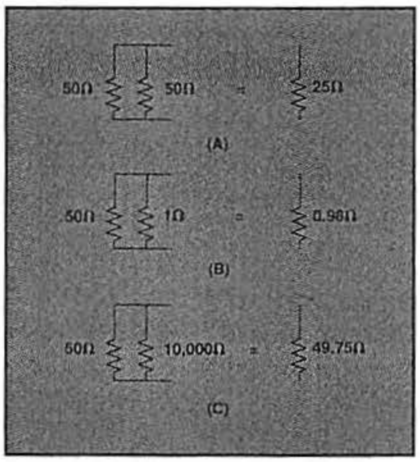

Figure 1. A duplexer uses impedance differences to isolate the transmitter and receiver. At (A), two 50Ω resistors or 50Ω coaxial cables wired in parallel have a resulting impedance of 25Ω. When connected to another 50Ω device, the connection represents an impedance mismatch and results in a power loss. At (B), when a 50Ω impedance circuit is connected in parallel with a 1Ω impedance circuit, the combined impedance is extremely close to 1Ω, almost a short circuit. At (C), when a 50Ω impedance circuit is connected in parallel with a 10,000Ω impedance circuit, the combined impedance is extremely close to 50Ω, meaning that there is little effect upon the 50Ω circuit's impedance.

A duplexer allows the use of a single antenna for transmitting and receiving simultaneously, as a repeater usually does.

Duplexers come in many shapes, sizes and types from many manufacturers. They often are described in antenna catalogs. Duplexers also may be called filters, combiners and cavities. Many people consider them to be mystical things that only engineers know about.

Duplexers, including filters, reject, pass and other "cavity devices," actually are quite straightforward once you understand the basics. The following describes the basics of filters, reject, pass and other "cavity filter devices."

Why is a duplexer required?

There are three reasons why a duplexer is used.

The first is to provide isolation between the transmitter and receiver.

The second is to preserve impedance matches among the antenna, transmitter and receiver. Impedance must be maintained at 50Ω to keep everything operating at maximum efficiency.

The third is to prevent several transmitters and receivers from interfering with each other and causing or receiving intermodulation products and other interference.

Isolation

In a mobile or base station radio, the transmitter and receiver do not operate at the same time.

When the receiver is on, and the channel is being monitored, the transmitter is turned off. When the operator presses the push-to-talk (PTT) button and transmits, the receiver is turned off.

A repeater receives a signal in the receiver and rebroadcasts the audio through the transmitter at the same time. This type of operation is called full-duplex because the transmitter and receiver are both on and operating at the same time. Full-duplex operation gives its name to the "duplexer."

Note that the receiver is receiving a signal of only a few microvolts (extremely small). The transmitter is transmitting a signal of several volts (extremely large). What is required is a device to separate or to isolate the receiver from the transmitter so that the two can operate at the same time without interfering with each other.

The receiver must continue to receive extremely small signals while the transmitter transmits extremely large signals. That is where the duplexer comes in. It will provide the required isolation between transmit and receive frequencies.

As an example of isolation, consider a 25W repeater package. The transmitter operates at a power level of 25W or +44.0dBm. The receiver is rated at 0.5μV or −113.0dBm. The difference between these two signal levels is 157dB.

The repeater must operate at both of these power levels. Using two different frequencies provides a certain amount of isolation. A duplexer provides additional isolation so that the repeater can operate in full-duplex mode.

A duplexer prevents receiver desensitization (desense) from occurring. That means that the receiver is as sensitive when the transmitter is on as when the transmitter is off.

How much isolation?

How much isolation is necessary depends on two factors: the amount of frequency separation between transmitter and receiver, and the transmitter output power.

Frequency separation is the main

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governing factor. Manufacturers graph *duplex curves* for each radio they produce. These curves tell you how much transmitter noise is produced by a transmitter at a given receiver separation from the transmit frequency. Sometimes these curves are available from the manufacturer; sometimes they are not.

The manufacturer always specifies *adjacent channel selectivity*. This specification can be used as a guideline. Adjacent channel selectivity is usually specified for either 25kHz or 30kHz channel spacing, and that is the spec that can be used.

Transmit power is the other factor. The more transmit power, the more isolation required. All calculations should be based on maximum transmit output power. Otherwise, turning the power up on the transmitter causes receiver desense, and the repeater will not operate properly.

As an example, take the same 25W transmitter as before.

25W = +44.0dBm
0.5μV = −(−113.0dBm)
Receiver selectivity = −85dB

Minimum required isolation = 72.0dB
3dB safety factor = 3.0dB

Total isolation required = 75.0dB

As a rule of thumb, when using this method, make sure that you have at least 3dB additional isolation to allow for any increase in transmitter power or decrease of receiver rejection in the future. In this case, isolation should be 72.0dB + 3.0dB = 75dB minimum.

If the transmitter power is increased to 50W, (+3dB) then isolation must be increased the same amount, by +3dB, to 75dB.

In this example, look for a duplexer specified as having a minimum of 75dB isolation. Note that, depending on frequency spacing, the amount of isolation required may or may not be available.

As a rule, at VHF, 300kHz is the minimum channel spacing that can be used in any repeater system. At UHF, a minimum frequency spacing of 3MHz is required.

Impedance

The duplexer uses impedance differences to isolate the transmitter and receiver.

For example, two 50Ω resistors or 50Ω coaxial cables wired in parallel have a resulting impedance of 25Ω. (See Figure 1A on page 10.) When connected to another 50Ω device, the connection represents an impedance mismatch and results in a power loss.

When a 50Ω impedance circuit is connected in parallel with a 1Ω impedance circuit, the combined impedance is extremely close to 1Ω, almost a short circuit. (See Figure 1B).

When a 50Ω impedance circuit is connected in parallel with a 10,000Ω impedance circuit, the combined impedance is extremely close to 50Ω, meaning that there is little effect upon the 50Ω circuit's impedance. (See Figure 1C.)

Duplexers are tuned devices.

They can present a 50Ω impedance at one frequency and either a lower or a higher impedance at another frequency. To provide isolation between two frequencies, a duplexer presents a short or an open circuit to a transmission line at a particular frequency. Energy at that frequency then either is removed from a transmission line or is prevented from traveling through the transmission line.

Next: Applications for types of duplexers are described to help you choose and configure cavities for specific purposes. Frequency bands and frequency separation play a part in selecting the cavities.

How to use duplexers: The various types

Part 2—Applications for types of duplexers are described to help you choose and configure cavities for specific purposes. Frequency bands and frequency separation play a part in selecting the cavities.

By Brian J. Henderson, P. Eng.

Duplexers allow transmitters and receivers to operate simultaneously and to use the same antenna, as they do in typical repeater installations.

Various configurations can be used to filter interference, too.

The bandpass cavity

The bandpass cavity is the easiest type of duplexer to explain and to understand.

First, imagine a transmitter and receiver antenna separated by some distance. (See Figure 1A to the right.) The transmitter transmits energy that is radiated by the antenna and received by the receiver antenna and receiver. There is a loss between the two antennas.

If these two antennas were contained inside a cylinder, the losses between them would be reduced. Instead of the transmitting antenna radiating some energy in all directions, most of the energy would be contained inside the cylinder. Most of the energy would be picked up by the receiving antenna. Losses are reduced. (See Figure 1B).

The cylinder's length and volume affect the transmission path between the two antennas. This path between the two antennas is quite sharp and pronounced.

If the antennas are simple "loops" or short dipoles on opposite sides of a cylinder and the volume of the cylinder is adjusted by a conductive rod in the middle, the previously imaginary configuration has become a bandpass cavity filter. (See Figure 1C).

The bandpass cavity filter's frequency response is shown in Figure 2 top right.

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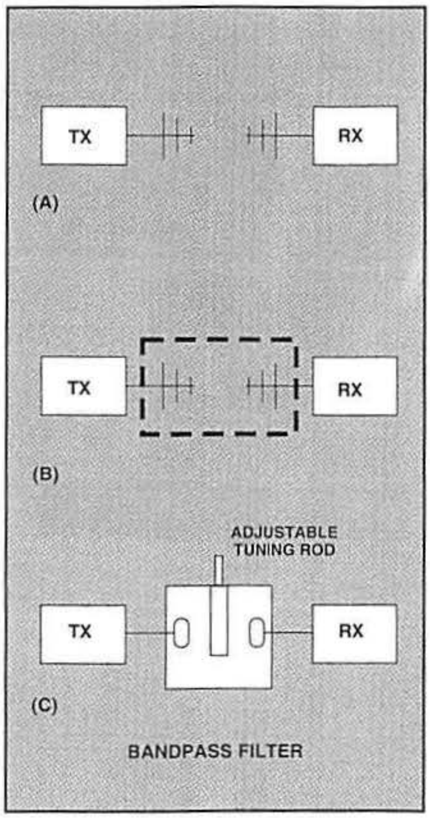


Figure 1. At (A), radio energy transferred between a transmitter antenna and receiver antenna is subject to a loss. If the antennas were within a cylinder, as in (B), the loss would be reduced. The cylinder's length and volume affect the transmission path between the two antennas. If the antennas are simple 'loops' or short dipoles on opposite sides of a cylinder, and the volume of the cylinder is adjusted by a conductive rod in the middle, the previously imaginary configuration has become a bandpass cavity filter, as in 1C.

The bandpass cavity can be adjusted for frequency by adjusting a "trombone slide" inside the cavity. Loss between the transmit and receive ports is at a minimum at the bandpass frequency and increases beyond the cavity's passband.

In addition, the SWR is at a minimum at the tuned frequency. SWR rises outside the bandpass cavity's passband.

Note that the physical diameter of the

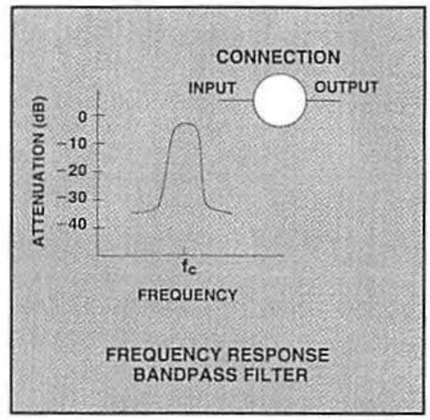


Figure 2. This is the frequency response of the bandpass cavity filter in Figure 1. The cavity can be adjusted for frequency by adjusting a "trombone slide" inside the cavity. Loss between the transmit and receive ports is at a minimum at the bandpass frequency and increases beyond the cavity's passband.

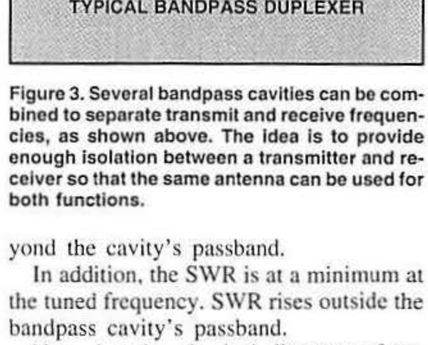


Figure 3. Several bandpass cavities can be combined to separate transmit and receive frequencies, as shown above. The idea is to provide enough isolation between a transmitter and receiver so that the same antenna can be used for both functions.

cavity has the effect of increasing the circuit "Q." The larger the diameter, the narrower the bandpass cavity and the higher the "Q." A 7-inch cavity is a better bandpass filter than a 5-inch cavity. A 10-inch cavity is better yet.

The bandpass duplexer

The function of a bandpass cavity has now been explained. So what does this do for the duplexer?

Several bandpass cavities can be combined to separate transmit and receive frequencies. The idea is to provide enough isolation between a transmitter and receiver so that the same antenna can be used for both functions. Such a duplexer is shown in Figure 3 on page 18.

Generally, two bandpass cavities are used in the transmit leg, and two are used in the receive leg of a repeater. Duplexers are connected in series with transmit and receive ports, as shown in Figure 3. The antenna port simply uses a "T" connector to parallel transmit and receive cables.

There is an advantage to using bandpass cavities to build a duplexer. The passbands of both the transmitter and receiver are narrowed.

In the case of the receiver, interference and intermodulation outside the passband of the receive cavities is reduced. Interference to other systems from your transmitter will be reduced.

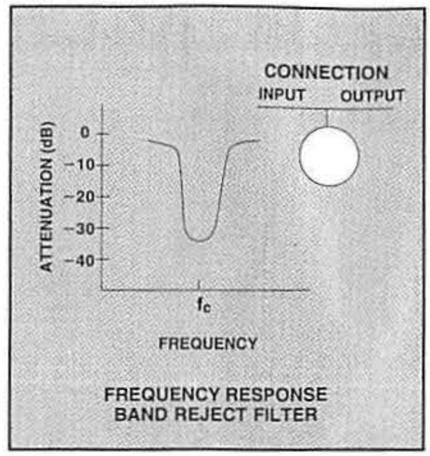


Figure 4. A reject cavity is a bandpass cavity with only one connector. The other connector either is left open or is omitted. The cavity's spectrum plot and connection diagram are shown above.

There is one drawback to using bandpass cavities for a duplexer. Practical limits on construction constrain transmit-receive spacing to less than 2MHz at VHF and 5MHz at UHF frequencies. Bandpass filters do not provide enough isolation for closer transmit-receive frequency spacing.

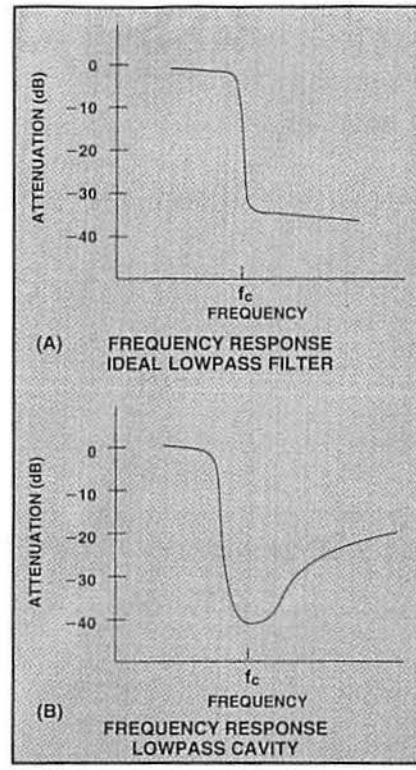


Figure 5. The graph at (A) shows the theoretical performance of a lowpass filter. It has a defined cutoff frequency. Below that frequency, signals pass with little loss. Above that frequency, signals are shorted out and do not pass through. A lowpass filter can be made by adding a capacitor in series with a bandpass cavity's feed loop. The pattern shown at (B) is that of a lowpass filter.

The reject cavity

Another common type of filter is called a reject cavity.

A reject cavity is simply a bandpass cavity with only one connector. The other connector either is left open or is omitted. See the spectrum plot and connection diagram shown in Figure 4 above left.

When connected into a transmission line with a "T" connector to "short out" a single frequency, the reject cavity removes the frequency from the line. This method commonly is used when another transmitter interferes with a receiver. A reject cavity is connected into the receive path to "notch out" the offending signal.

The lowpass filter

Another type of filter commonly used is the lowpass filter.

The theoretical performance of a lowpass filter is shown in Figure 5A above right. A lowpass filter has a defined cutoff frequency. Below that frequency, signals

pass with little loss. Above that frequency, signals are shorted out and do not pass through.

A lowpass filter can be made by adding a capacitor in series with a bandpass cavity's feed loop. The pattern shown in Figure 5B is that of a lowpass filter.

The highpass filter

A highpass filter is the opposite of a lowpass filter.

Signals above the cutoff frequency pass through with little loss, and signals below the cutoff frequency are shorted out and do not pass through the highpass filter. (See Figure 6A to the right.)

The highpass filter also can be made by adding a capacitor in series with a reject cavity's feed loop. The pattern shown in Figure 6B is that of a highpass filter.

Note that the highpass and lowpass filters have exactly the same construction.

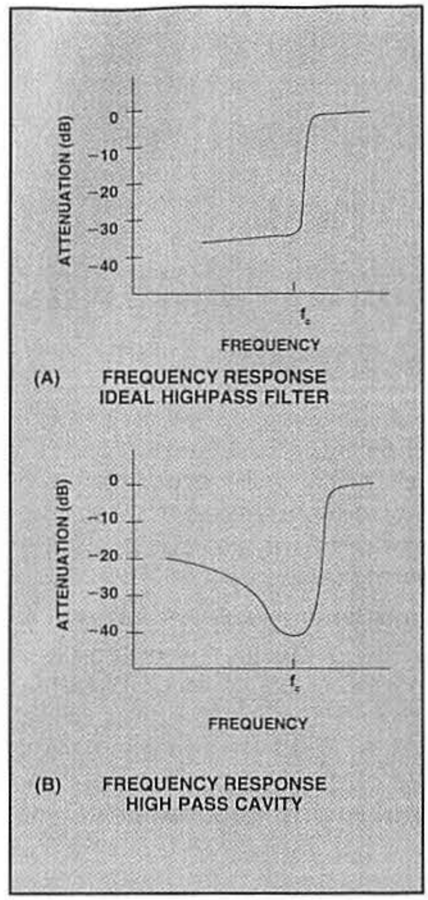


Figure 6. A highpass filter is the opposite of a lowpass filter. As shown at (A), signals above the cutoff frequency pass through with little loss, and signals below the cutoff frequency are shorted out and do not pass through the highpass filter. The highpass filter also can be made by adding a capacitor in series with a reject cavity's feed loop. The pattern shown at (B) is that of a highpass filter.

Near the feed connector on a filter you will see a small screw for adjusting the capacitor.

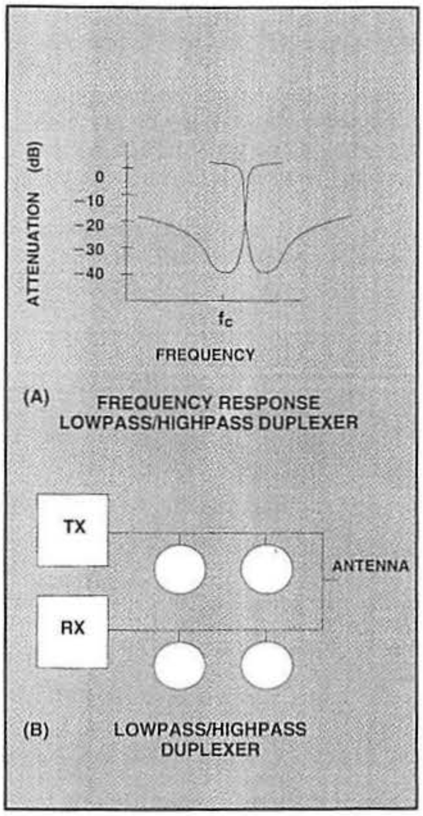
The capacitor setting determines whether the filter is a highpass or lowpass device, and it is not possible to tell from a visual inspection which type the cavity is. The only way to tell is by looking at the display of the cavity on a spectrum analyzer.

The bandpass/band-reject cavity

Highpass and lowpass filters could be combined together to form a duplexer.

There is a better way. A proper capacitor choice makes the filter a combination lowpass-highpass and bandpass filter, depending on the capacitor setting. (See Figures 5B and 6B.)

In this way, a single cavity connected to a receiver, for example, can pass the receive frequency with little loss and reject the transmit frequency. This forms the



basis of the typical highpass-lowpass duplexer.

The bandpass/band-reject duplexer

Remember the isolation calculations performed earlier?

To get the 70dB–75dB of isolation required, two bandpass/band-reject cavities can be connected into each of the repeater's transmit and receive legs. (See Figure 7 to the left.)

Two cavities in the transmit side and two cavities in the receive side provide the required 70dB–75dB of isolation. In this case, minimum frequency separation is about 500kHz.

If a frequency spacing less than 500kHz is required, three cavities can be used on each side. This configuration increases isolation to about 90dB. The minimum frequency separation is about 300kHz at VHF. This separation is a practical limit of this type of duplexer. Adding more cavities increases the loss while providing little additional rejection.

Next: How duplexers are constructed and how they are installed have much to do with their tuning and frequency stability. Suggestions are included for ordering duplexers and for initial tuning or retuning.

Figure 7. Remember the isolation calculations described in the text? To get the 70dB–75dB of isolation required, two bandpass/band-reject cavities can be connected into each of the repeater's transmit and receive legs, as shown to the left. Two cavities in the transmit side and two cavities in the receive side provide the required 70dB–75dB of isolation. In this case, minimum frequency separation is about 500kHz.

Duplexer series

The previous installment in this article series is "How to use duplexers: Isolation requirements" in the July 1994 issue.

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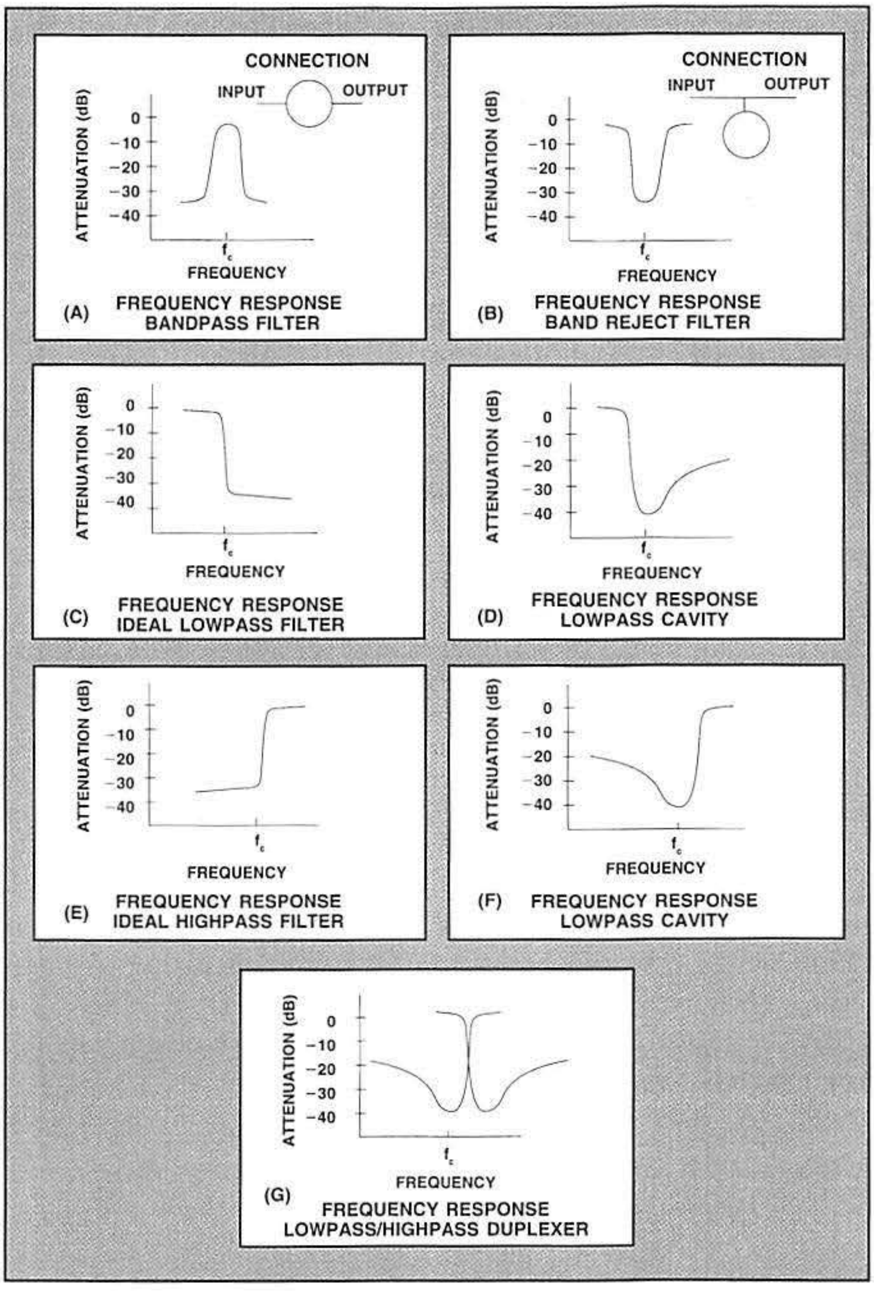
How to use duplexers: Installing and tuning

Part 3—How duplexers are constructed and how they are installed have much to do with their tuning and frequency stability. Here are tips for ordering duplexers and for initial tuning or retuning.



By Brian J. Henderson, P. Eng.

Whether duplexers are used in a typical manner to support repeater operation or as filters to reduce or eliminate interference, their construction, installation and tuning affect the outcome.

Temperature

Temperature plays a big part in duplexer performance.

The volume of the cavity is extremely critical to duplexer tuning. A small temperature change can contract or expand cavity components, shifting the duplexer frequency as much as 30kHz–40kHz, enough to shut down a repeater system.

The system cannot be allowed to shut down because of a duplexer temperature problem. What do you do?

The first thing is to make sure the temperature in your repeater building remains relatively constant. Install a thermostat on an electric heater to heat a small building. Keep duplexers themselves out of drafts and away from ventilation fans and windows. Keep them out of sunlight so they are not subject to heating during the day and cooling at night.

Physical construction of duplexers

There are two methods of duplexer construction.

Figure 1. The easiest way to understand the use of a spectrum analyzer and tracking generator for cavity tuning is by example. Attenuation vs. frequency curves for bandpass and band-reject cavities are shown in (A) through (G) to the left.

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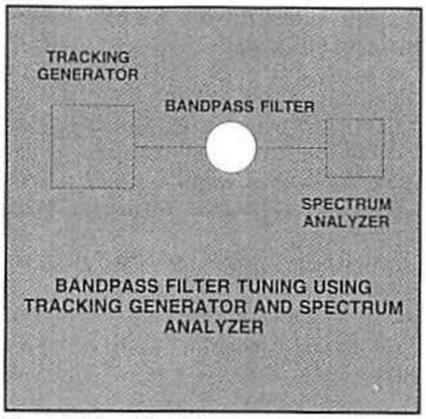

Figure 2. To replicate the example of cavity tuning described in the text, connect a tracking generator and spectrum analyzer as shown.

The older method uses round containers and associated internal components. These duplexers are more difficult to mount on equipment racks because of their shape.

Manufacturers then developed rectangular duplexers. They are compact and far more convenient for rack-mounting.

When round cavities are exposed to temperature changes, they expand equally in all directions. Tuning may or may not be affected.

When a rectangular cavity changes temperature, it expands more in one direction than another, which is certain to affect its tuning.

Generally speaking, where temperature extremes are expected, such as for unheated mountaintop locations, use a round cavity filter.

Coaxial cable

There are several factors to consider when using coaxial cable to connect cavities to make a duplexer.

(1) To preserve as much isolation as possible, always use double-shielded cable.

Use either RG-214/U or RG-400/U cable for all connections. It is a good idea to use these types of cable as jumper cables to the radio repeater and antenna connections. This keeps RF signals where they should be—inside the radio and antennas.

(2) Cable length is important.

Do not use random-length jumper cables. All cable lengths are to be either a quarter-wavelength ($\frac{1}{4}\lambda$) or a half-wavelength ($\frac{1}{2}\lambda$) to maintain the impedance presented by a cavity to the line.

(3) When calculating the cable length, take into account the cable's *velocity factor.*

When RF travels in a cable, it slows down. The difference between its velocity in free space or air and its velocity

in cable is the cable's velocity factor, expressed as a percentage.

Cable impedance and length

The coaxial cable jumper length affects the impedance at each end of the cable. Half-wavelength cables have an identical impedance at each end; quarter-wavelength cables have an opposite impedance.

For example, if the impedance at one end of a $1/2\lambda$ cable is high (band-reject), the impedance at the other end will be high.

If the impedance at one end of a $1/4\lambda$ cable is high, the impedance at the other end will be low.

Remember these rules when moving or separating cavities on an equipment rack and changing their connecting cable lengths.

For band-reject cavities, use $1/4\lambda$ cables. Bandpass cavities and cables between radio and filters should be $1/2\lambda$ long.

The spectrum analyzer

A spectrum analyzer with a tracking generator can be used for tuning duplexers.

A spectrum analyzer is similar to an oscilloscope. It displays frequency on the horizontal axis vs. amplitude on the vertical axis. Because duplexers are frequency-and-amplitude-dependent, the spectrum analyzer is ideal for tuning and aligning them.

The easiest way to understand the use of a spectrum analyzer and tracking generator is by example. Attenuation vs. frequency curves for bandpass and band-reject cavities are shown in Figure 1 on page 24.

As the name implies, a bandpass cavity has low attenuation at its bandpass frequency. Other frequencies are attenuated.

Duplexer series

Previous installments in this article series include:

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The farther from the cavity's center frequency, the higher the attenuation.

A band-reject cavity is the opposite. A single frequency is rejected or "shorted out" of the circuit. Maximum attenuation occurs at the reject frequency. The further from the cavity's center frequency, the lower the attenuation.

Filter tuning

How can this information be used for tuning?

Remember the cavity configuration—*bandpass* or *band-reject*. Use the tracking generator and analyzer to produce the correct frequency curve as shown on the spectrum analyzer.

For example, consider a bandpass cavity to be tuned to a center frequency of 153.620MHz. Set the spectrum analyzer for a center display frequency of 153.620MHz. Connect the tracking generator and spectrum analyzer as shown in Figure 2 on page 27.

Loosen the locking set screws or nuts on the cavity's tuning rod. Slide the rod in or out so that the attenuation is minimized around the analyzer display's center frequency. The cavity is now tuned. Figure 1A shows the display that should appear on the analyzer.

A reject cavity produces a reverse display. Again set the spectrum analyzer center frequency to, for example, 153.620MHz. Adjust the tuning rod so that the rejection notch on the display is centered and on the correct frequency. (See Figure 1B.)

If the cavity is a band pass/band-reject type, there are two adjustments to be made. Example frequencies are 153.62MHz (pass) and 154.22MHz (reject). The bandpass adjustment is set first using the cavity tuning rod. The band-reject is set by adjusting the capacitor.

The capacitor usually is right beside the input connector on the cavity itself. It must be adjusted using either a nylon or other non-inductive tuning tool. (See Figure 1D and 1F for lowpass and highpass response curves.)

Note that most highpass/lowpass cavities can be adjusted for either highpass or lowpass configurations within certain limits by watching the analyzer display while adjusting the capacitor.

The spectrum analyzer must be used to start the tuning process, and it gets you near the correct adjustments. The analyzer will indicate whether a cavity is set for highpass or lowpass.

At the factory, fine tuning is performed with a network analyzer and return loss bridge. When such equipment is unavailable, another fine-tuning method can be used with a transmitter, wattmeter and signal generator. The filters can then be put into service with a reasonable confidence level.

Tuning rods too short?

When tuning a filter, you may find that you "run out" of tuning rod.

To go lower in frequency, the tuning rod must be pushed into the cavity. You may reach a point where the end of the rod outside the cavity is too short to push it any farther, so the cavity cannot be adjusted any lower in frequency.

When a manufacturer builds a duplexer, all the rods initially are the same length. Depending on the frequency requested when the unit originally was ordered, some tuning rods may appear longer than others after tuning.

Most manufacturers then cut the rods so that they all protrude the same distance outside the cavity. This cutting is

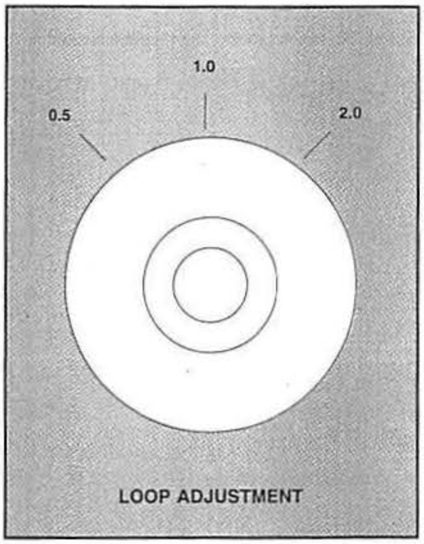

Figure 3. Inside the cavity, a loop connected to the cable connector forms the radiating and pickup element. The loop's position can change the cavity's performance. In newer cavities, the loop may be marked 0.5, 1.0 or 2.0. The loop turns when certain screws are removed. Turning the loop makes the cavity's frequency response sharper or wider as required. If an extremely selective cavity is required, rotate the loop while watching the spectrum analyzer display to narrow the cavity's bandwidth. See text for precautions.

for aesthetic reasons only. Cavities look better when their rods are an equal length—that is, if the cavity never is retuned.

Unfortunately, a cavity supplied with a cut rod may cause problems during tuning, especially when its operating frequency is moved much—from 165MHz to 151MHz, for example.

You have two options: Try to find a cavity with a longer tuning rod, or buy a new rod from the duplexer manufacturer, which can be expensive.

When ordering filters, it is a good idea to specify on your purchase order: "Tuning rods not to be cut." That way, if the frequency ever has to be changed, options are left open for further tuning or adjustment.

Tuning loops

Inside the cavity is a loop connected to the cable connector that forms the radiating and pickup element.

The loop's position can change the cavity's performance. In newer cavities, the loop may be marked 0.5, 1.0 or 2.0. The loop turns when certain screws are removed. (See Figure 3 to the left.)

Turning the loop makes the cavity's frequency response sharper or wider as required. If an extremely selective cavity is required, rotate the loop while watching the spectrum analyzer display to narrow the cavity's bandwidth.

There is a trade-off. If the loop is rotated for a narrower passband, for example, insertion loss increases. Numbers on the cavity refer to its insertion loss measured in decibels. Note that if the cavity is a bandpass type, both loops must be rotated to, for example, the 1.0dB position. Otherwise, loss will increase substantially. The cavity must remain symmetrical for proper operation.

Loop size

Tuning loops themselves are a particular length, depending on frequency.

Making a big change in frequency may require changing the loop size as determined by the manufacturer. When new loops are required, contact the manufacturer for parts and components.

Next: After initially tuning a filter using a spectrum analyzer and the technique described above, steps described in Part 4 can be used with inexpensive test equipment for fine-tuning.

How to use duplexers: Fine-tuning adjustments

Part 4—After initially tuning a filter using a spectrum analyzer and the technique described in Part 3, follow these fine-tuning steps to finish the job. Inexpensive test equipment can be used.

By Brian J. Henderson, P. Eng.

The best method for tuning filters uses thousands of dollars worth of test equipment.

Another, less expensive method, uses a transmitter, receiver, directional wattmeter and signal generator. One or more dummy loads may be required for a duplexer's unused ports.

Several rules and facts apply to this tuning method.

(1) All duplexer ports, whether or not they are connected to a signal generator, transmitter or receiver, must be terminated in a 50Ω impedance.

This rule cannot be stressed enough. Failure to follow this one simple rule results in poor filter tuning and poor system performance.

(2) When tuning any bandpass cavity, the lowest SWR point occurs at the passband frequency.

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(3) Once the tuning rod is adjusted for the correct frequency in a pass or reject cavity, capacitor adjustment does not affect this tuning.

That is, once the tuning rod is set for pass frequency, this adjustment is not affected further by adjustment of the tuning capacitor, other ports of the duplexer string or other cavities.

Bandpass Duplexer

The first type of duplexer to be tuned is the bandpass duplexer. There is only one adjustment per cavity. Connect transmitter, wattmeter and terminations as shown in Figure 1 below.

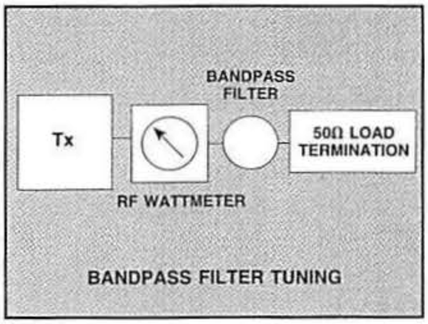

Figure 1. To configure equipment for tuning a bandpass duplexer, connect a transmitter, a wattmeter and terminations as shown.

Set the transmitter to the correct pass frequency. Transmit into the duplexer string and adjust the tuning rods for minimum reflected power as indicated on the wattmeter. Note that reflected powers should be less than 1W, so it may be advisable to use a low-power wattmeter element.

Tune each bandpass cavity in the above manner. Then assemble all bandpass cavities together into the correct duplexer configuration. Fine-tune the transmit side as shown in Figure 2 below left.

Then reverse the transmitter and load connections. Set the transmitter to the receive frequency and adjust the receive side in the same manner. It is perfectly acceptable to transmit into the receive side of any duplexer, providing all terminations are in place and the receiver is not connected.

As a check for proper isolation, connect the signal generator, receiver and terminations as shown in Figure 3 below right. Set the signal generator and receiver to the same frequency.

Inject the signal into the duplexer antenna port. In this example, the signal

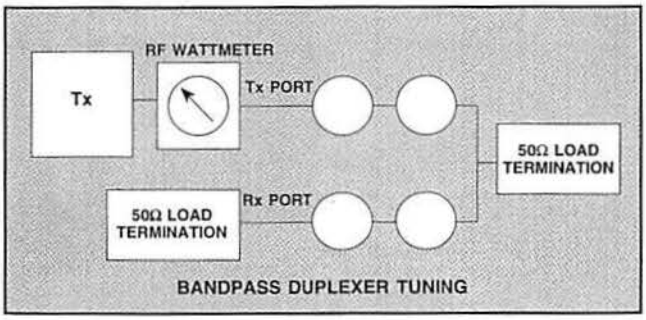

Figure 2. After tuning each bandpass cavity individually, assemble them into the correct duplexer configuration. Fine-tune the transmit side as shown. Then reverse the transmitter and load connections. Set the transmitter to the receive frequency and adjust the receive side in the same manner.

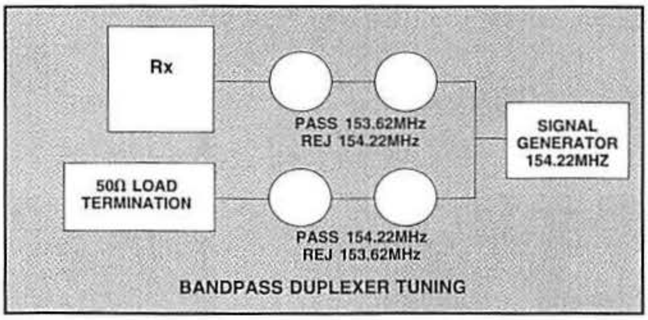

Figure 3. As a check for proper isolation, connect the signal generator, receiver and terminations as shown. Follow steps described in the text to measure the duplexer isolation.

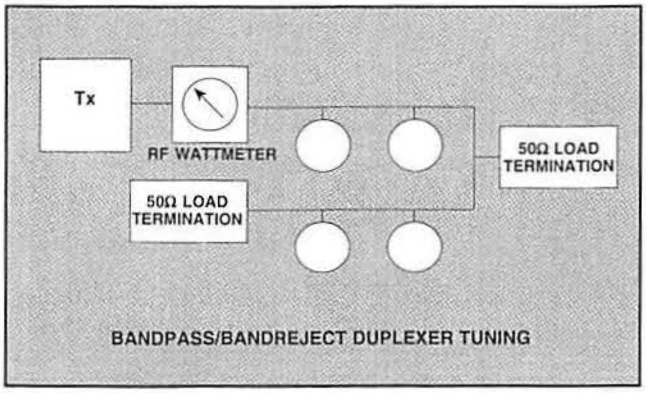

Figure 4. Steps for tuning the bandpass/bandreject duplexer are similar to those for the bandpass duplexer. Set up the duplexer as shown, and follow the steps described in the text.

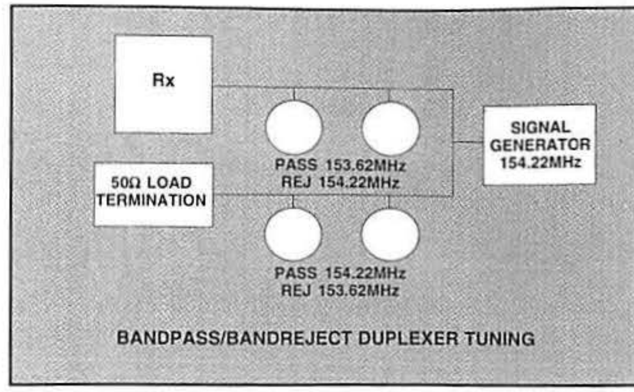

Figure 5. Use this equipment configuration to measure the receiver noise threshold in Step 2 of the bandpass/bandreject duplexer adjustment procedure.

generator and receiver are set to 153.62MHz. Determine receiver *noise threshold* (the point where noise begins to disappear). Record this reading in dBm.

Move the signal generator to the duplexer transmit port. Retune the signal generator and receiver to 154.22MHz. Increase generator output until the same noise threshold point is found. Again, record the generator output level in dBm.

The difference between these two levels is the duplexer isolation in dB at that frequency.

Bandpass/bandreject duplexer

Tuning this type of duplexer is similar to the bandpass type.

Two adjustments are made on each cavity, the tuning rod and the capacitor adjustment. Set up the duplexer as shown in Figure 4 above left. In all cases, bandpass tuning rods are adjusted first; capacitors are adjusted last.

(1) Transmit into the duplexer on the correct frequency.

Adjust the tuning rods for minimum reflected power. Tune both "sides" of the duplexer—transmit and receive—on the correct frequency.

(2) Connect the signal generator to the antenna port. (See Figure 5 above right.)

Inject signal on the other frequency and adjust the capacitor for maximum rejection

of this signal.

Open the receiver squelch.

Increase signal generator output until normal FM quieting is heard. Reduce generator output until noise returns. This is referred to as the receiver *noise threshold.*

(3) Adjust the capacitor for maximum noise as heard in the receiver. (This point represents the maximum attenuation of signal from the signal generator.)

(4) Keep increasing generator output and adjusting capacitors until no further increase in rejection can be obtained.

(5) Repeat this process for the other "half" of the duplexer string.

You may find one of these types of duplexers impossible to tune. If so, check the duplexer with a spectrum analyzer and tracking generator. The duplexer may have been "flipped" from a highpass to a lowpass or vice versa. See Figure 6 to the right for the proper appearance of highpass and lowpass curves as shown on a spectrum analyzer display.

Remember that tuning a duplexer with a spectrum analyzer is *approximate.* Duplexers must be *fine-tuned* with the transmitter and receiver technique detailed above.

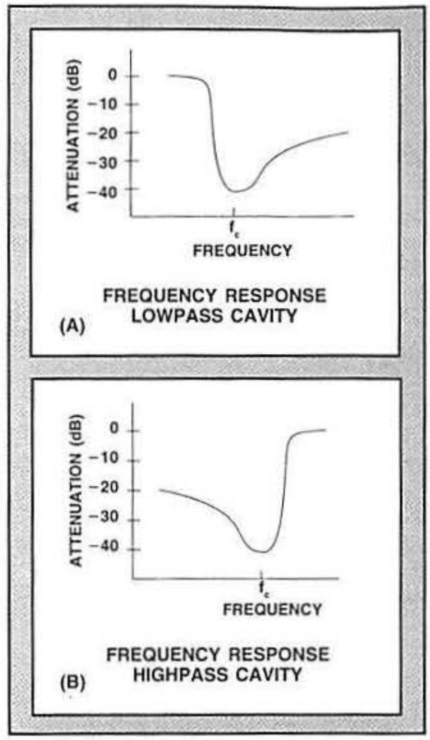

Figure 6. The spectrum analyzer display for a lowpass curve should look like curve (A), and the highpass curve should look like curve (B).

Next: Transmitter combiners and receiver multicouplers allow multiple repeaters to share the same antenna. If the system can tolerate the energy loss, combiners allow more efficient use of antenna space.

Duplexer series

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How to use duplexers: Combiners, multicouplers

Part 5—Transmitter combiners and receiver multicouplers allow multiple repeaters to share the same antenna. If the system can tolerate the energy loss, combiners allow more efficient use of antenna space.

By Brian J. Henderson, P. Eng.

Transmitter combiners and receiver multicouplers are filter configurations.

A duplexer allows a transmitter and receiver to use a single antenna simultaneously. A transmitter combiner allows several transmitters to use the same antenna without interfering with each other; a receiver multicoupler does the same for receivers. Where tower space is at a premium, a combiner and a multicoupler may allow additional radios to use previously installed antennas.

When interference occurs between some transmitters or receivers at a radio site, a combiner and multicoupler system reduces the interference. Interference is common on radio towers with separate antennas for each repeater system. The isolation of a combiner and multicoupler system may be required to prevent intermodulation products (intermod) from occurring.

Combiner systems have losses. A combiner system allows additional transmitters and receivers to use the same antenna.

A combiner system may be warranted if:

- the tower is loaded with antennas.
- interference between systems is occurring.
- the tower must be rebuilt to accommodate more radio systems.

A combiner system may be expensive and it may introduce system losses that affect radio coverage. These factors must be considered before installing a combiner option. On the other hand, using combiners may cost less than rebuilding a tower to accommodate more antennas or radio systems.

Henderson is senior engineer, communications, with Canadian Western Natural Gas, Calgary, Alberta.

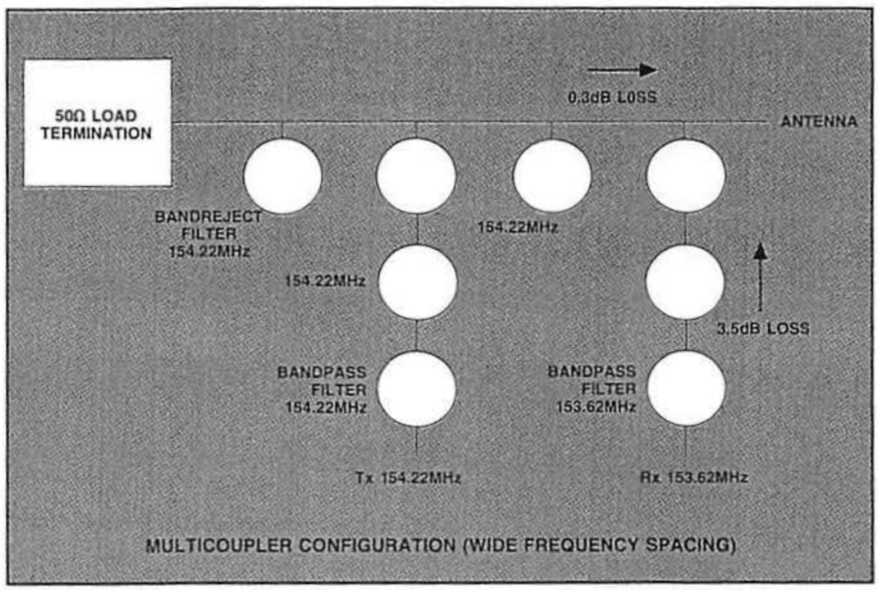

Figure 1. A typical bandpass/band-reject combiner is configured as shown. It includes two or three bandpass cavities and one reject cavity per frequency. Because of the combiner's bandpass nature, the minimum frequency separation is 2MHz. For closer frequency spacing, use the bandpass/isolator type of combiner configuration.

There are two basic combiner types.

Whether to use either either depends on transmitter and receiver frequency spacing.

As with duplexers, a combiner's purpose is to provide sufficient isolation between transmitters and receivers so that they operate without mutual interference.

Bandpass/band-reject combiner

Figure 1 above is a general drawing of a bandpass/band-reject combiner.

This combiner type has two or three bandpass cavities and one reject cavity per frequency. Because of the combiner's bandpass nature, the minimum frequency separation is 2MHz. For closer frequency spacing, use the bandpass/isolator type of combiner configuration.

Note as well that each "leg" of the system has approximately 3.5dB of loss plus 0.3dB system loss between each connection point and the antenna. That loss is why receivers are placed on the "string" first, followed by the transmitters. The idea is to reduce loss between the antenna and receiver.

Tuning these combiner strings consists of tuning individual bandpass and band-reject cavities. Once tuned to the correct frequency using a transmitter and wattmeter as described above, the combiner can be installed. Remember to terminate all unused ports with a 50Ω load.

The combiner can be expanded to add more transmitters and receivers. Figure 1 shows one section of a combiner string. This section allows one transmitter and one receiver to operate.

Adding another eight individual cavities

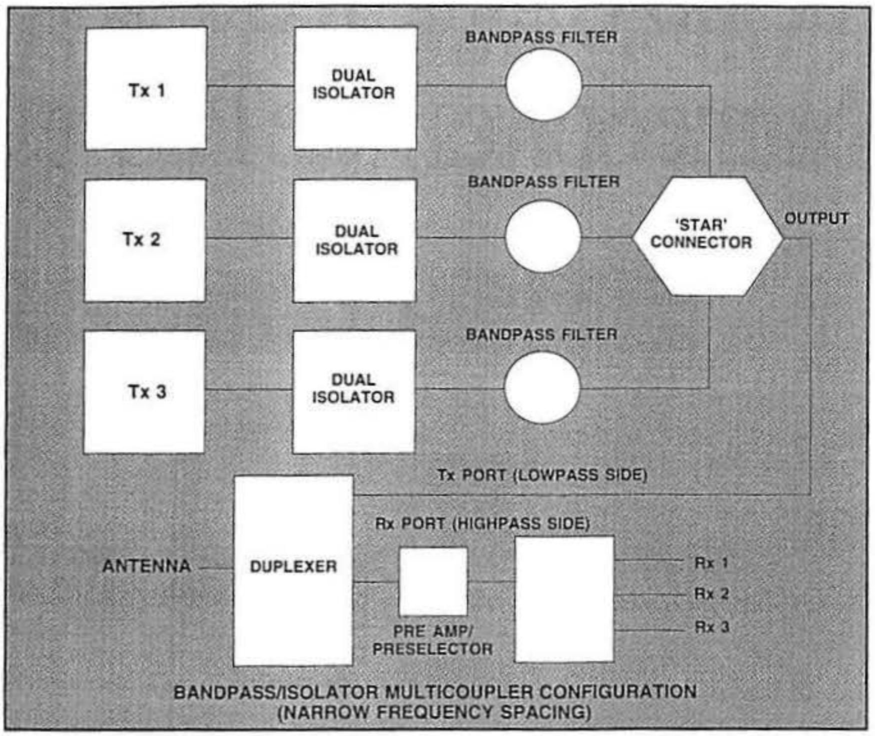

Figure 2. A typical bandpass-isolator combiner is configured as shown. It can be used for frequency spacings closer than 2MHz. An operational limit is a minimum spacing of 500kHz at VHF and 300kHz at UHF. For cellular use, channel spacing as close as 250kHz is possible.

and moving the 50Ω load termination to the rear of the combiner string allows one more transmitter and receiver to be added. Remember to connect the receivers ahead of all transmitters to minimize loss between the antenna and receivers.

The string can be expanded to accommodate as many as four transmitters and four receivers on a single antenna. This is a practical limit because of loss.

The last transmitter in the combiner string (just before the load termination) will experience $8 \times 0.3dB + 3.5dB = 5.9dB$ of loss. More transmitters can be added if the system can tolerate the loss. Normally, four is the maximum number of repeaters used because of the loss.

Bandpass-isolator combiner

The bandpass-isolator type of combiner combination can be used for frequency spacings closer than 2MHz.

An operational limit is a minimum spacing of 500kHz at VHF and 300kHz at UHF. For cellular use, channel spacing as close as 250kHz is possible. Figure 2 to the left is a drawing of a typical bandpass-isolator combiner configuration.

Several frequency restrictions apply to using this combiner type:

(1) The minimum frequency spacing is 500kHz at VHF and 250kHz at UHF.

(2) All transmit frequencies must fall into the passband on one side of a duplexer.

(3) All receive frequencies must fall into the passband on the other side of the duplexer.

(4) Frequencies cannot be scattered throughout a given VHF or UHF frequency band.

There are four basic components to this type of combiner:

(1) ferrite isolator.

(2) bandpass filter.

(3) duplexer.

(4) receiver multicoupler.

The duplexer's purpose is to separate the transmitter frequency group from the receive frequency group. The duplexer can be either type, depending on the overall transmitter and receiver frequencies' bandwidth requirements.

Transmitters are connected first to a dual isolator, then to a bandpass filter. From there, they are connected to a "star connector," which is similar to a "T" connector except with four or more connection ports. Several cables can be connected in parallel because they represent several circuits connected in parallel with a 50Ω circuit. There is no effect on the impedance at a particular frequency. Note also that unused ports should be left open rather than terminated to preserve isolation and impedance.

Tuning

The bandpass-isolator combiner has only two components that can be tuned in the field.

First, the duplexer can be tuned as described for the type and configuration of the duplexer in use. The bandpass filter can be tuned in the conventional manner as described above for bandpass cavities.

Ferrite isolators should not be adjusted. They usually have enough bandwidth to use without tuning.*

The receiver multicoupler is made of a bandpass network, an amplifier and splitter. The only component that can be adjusted is the bandpass network, if required. The bandwidth usually is quite wide, so adjustment may or may not be necessary depending on how much frequency shift there is among all receivers.

Try injecting signal into a receiver through the receiver multicoupler. If the receiver operates with reasonable sensitivity, leave the bandpass filter alone. If it works, don't fix it.

Duplexer

When combining several transmitters and receivers in this way, it still is necessary to provide separation between the transmitter and receiver groups of frequencies. The easiest way to do this is with another duplexer. Still, make sure that transmitter and receiver frequencies fall into a group that can be separated by a duplexer.

As an example, consider a system with the following operating frequencies:

SYSTEM	TRANSMIT FREQUENCY (MHz)	RECEIVE FREQUENCY (MHz)
1	413.1000	418.1000
2	413.3000	418.3000
3	413.5000	418.5000
4	413.7000	418.7000

In this case, all transmitter frequencies fall into the 413.1000MHz–413.7000MHz

*See "Technically Speaking" by Harold Kinley, C.E.T., in the June and July 1993 issues.

range. Receive frequencies fall into the 418.1000MHz–418.7000MHz range. A bandpass-style duplexer with a 600kHz passband bandwidth will work fine.

A spectrum analyzer and tracking generator must be used to align this duplexer. Adjust for required passbands on both the transmit and receive sides.

If frequencies are scattered throughout the band, it is not possible to use this multicoupling system type. There are no other alternatives besides separate antennas.

Shipping and handling

You have a duplexer or combiner tuned up and ready to travel to the site. You have made sure that all adjustments are locked and tightened. You throw it in the back of the truck, and off you go. You get to the site, install it and find that it does not work. Now what?

Two things can happen to duplexers or combiners in transit to detune them.

All tuning rods on duplexers have either a set screw or a locking nut to tighten their adjustments. Capacitors do not. They can move if bounced around or jarred. When they move, the cavity is detuned.

The other thing that can happen is that the tuning rod can shift inside the cavity. When it does, the filter is detuned.

The rule is, take it easy with the equipment. It is fragile. If you have the original packing material and shipping crates, use them. Wrap all filters in foam rubber pads to cushion them when driving up the bumpy road to the radio site.

A temperature change may be a factor, too. Filters transported in winter may be cold when they arrive at the site, so let them warm up for 15-20 minutes before installing them. A small change in temperature can detune cavities. Once their temperature stabilizes, the filters should be back into proper tune.

A further note on temperature: Filter detuning is evident when filters are *operating* during extreme temperature changes. During *shipping*, temperature changes do not affect them. Once the filters return to room temperature, they should operate as specified.

Summary

There are many types of duplexers, cavities and isolators that can be used for transmitter and receiver isolation. The methods described in these five articles will assist with retuning cavities to provide the desired function with the antenna system.

(This concludes the article series.)

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